1. Introduction:

1.1. What is climate change?

Climate change is a long-term shift in the climate of a specific location, region or planet. The shift is measured by changes in features associated with average weather, such as temperature, wind patterns and precipitation. What most people don't know is that a change in the variability of climate is also considered as climate change, even if average weather conditions remain the same.

Climate change occurs when the climate of a specific area or planet is altered between two different periods of time. This usually occurs when something changes the total amount of the sun's energy absorbed by the earth's atmosphere and surface. It also happens when something changes the amount of heat energy from the earth's surface and atmosphere that escapes to space over an extended period of time.

Such changes can involve both changes in average weather conditions and changes in how much the weather varies around these averages. The changes can be caused by natural processes like volcanic eruptions, variations in the sun's intensity, or very slow changes in ocean circulation or land surfaces which occur on time scales of decades, centuries or longer.

But humans also cause climates to change by releasing greenhouse gases and aerosols into the atmosphere, by changing land surfaces, and by depleting the stratospheric ozone layer. Both natural and human factors that can cause climate change are called 'climate forcings', since they push, or 'force' the climate to shift to new values.

Climate change refers to general shifts in climate, including temperature, precipitation, winds, and other factors. Global warming refers specifically to any change in the global average surface temperature. Global warming does not mean that the world will be uniformly warmed up. In fact, an increase in average global temperature will also cause the circulation of the atmosphere to change, resulting in some areas of the world warming more, others less. Some areas can even cool.

1.2. What is the Greenhouse Effect?

A natural system known as the "greenhouse effect" regulates temperature on the Earth. Just as the ordinary glass keeps heat inside a glass greenhouse, our atmosphere traps the sun's heat near earth's surface, primarily through heat-trapping properties of certain "greenhouse gases" like Carbon dioxide, methane etc.

Earth is heated by sunlight. Most of the sun's energy (short wave energy) passes through the atmosphere, to warm the earth's surface, oceans and atmosphere. However, in order to keep the atmosphere's energy budget in balance, the warmed earth also emits heat energy back to space as infrared radiation.

As this energy radiates upward, most is absorbed by clouds and molecules of greenhouse gases in the lower atmosphere. These re-radiate the energy in all directions, some back towards the surface and some upward, where other molecules higher up can absorb the energy again. This process of absorption and re-emission is repeated until the energy escapes from the atmosphere to space.

However, because much of the energy has been recycled downward, surface temperatures become much warmer than if the greenhouse gases were absent from the atmosphere. This natural process is known as the greenhouse effect. Without greenhouse gases, Earth's average temperature would be -19°C instead of +14°C, **or 33°C colder**.

Over the past 10,000 years, the amount of greenhouse gases in our atmosphere has been relatively stable. Then a few centuries ago, their concentrations began to increase due to the increasing demand for energy caused by industrialization and rising populations, and due to changing land use and human settlement patterns.

1.3. What are the different greenhouse gases?

Water vapour is the most common greenhouse gas. There are other important gases. Some occur naturally and some come from human activity.
Carbon Dioxide or CO2 is the most significant greenhouse gas released by human activities, mostly through the burning of fossil fuels. It is the main contributor to climate change.
Methane is produced when vegetation is burned, digested or rotted with no oxygen present. Garbage dumps, rice or paddies, and grazing cows and other livestock etc. release lots of methane.
Nitrous oxide can be found naturally in the environment but human activities are increasing the amounts. Nitrous oxide is released when chemical fertilizers and manure are used in agriculture.
Halocarbons are a family of chemicals that include CFCs (which also damage the ozone layer), and other human-made chemicals that contain chlorine and fluorine.

1.4. When the greenhouse gases in the atmosphere are such a small percentage, why do they cause such a big effect on climate?

While 99% of the dry atmosphere consists of nitrogen and oxygen, the atmospheric greenhouse gases comprise of less than 1% in the atmosphere. But this tiny amount increases the earth's average surface temperature from -19°C to +14°C (a difference of about 33°C).

A little bit of increase of greenhouse gas makes a hell of change in the warming of atmosphere. As the concentration of greenhouse gases in the atmosphere is so low, a small increase in human emissions can have a significant effect. For example, human emissions of carbon dioxide (CO2) currently amount to roughly 28 billion tonnes per year. Scientists have estimated that over the next century human emissions will increase the concentration of carbon dioxide in the atmosphere from about 0.03% at present to almost a doubling (0.06%) or a tripling (0.09%) if the present rate of industrialization and fossil fuel burning continues.

1.5. What are natural forces that cause the climate change?

Earth’s climate also changes through natural causes. The changes in the intensity of sunlight reaching the earth cause cycles of warming and cooling. These cycles have been a regular feature of the Earth's climatic history. Some of these solar cycles - like the four glacial-interglacial swings during the past 400,000 years - extend over very long time scales and can have large amplitudes of 5 to 6°C. For the past 10,000 years, the earth has been in the warm interglacial phase of such a cycle. Other solar cycles are much shorter, with the shortest being the 11 year sunspot cycle.

Other natural causes of climate change include variations in ocean currents (which can alter the distribution of heat and precipitation) and large eruptions of volcanoes (which can sporadically increase the concentration of atmospheric particles, blocking out more sunlight).

Despite these natural causes, for thousands of years, the Earth’s atmosphere has changed only very little. So far necessary temperature and the balance of heat-trapping greenhouse gases have remained optimal for the survival of life on this planet. But today we’re having problems to keep this balance.

Because we burn fossil fuels to heat our homes, run our vehicles, produce electricity, and manufacture all sorts of products, we’re adding everyday more greenhouse gases to the atmosphere. By increasing the amount of these gases, we’ve enhanced the warming capability of the natural greenhouse effect.
It’s the human-induced and enhanced greenhouse effect that causes great concern today, because it has the potential to warm the planet at a rate that has never been experienced in human history.

1.6. What researchers say?

An international scientific consensus has emerged that our world is getting warmer. Abundant data demonstrate that global climate was warmed up during the past 150 years.

The increase in temperature was not constant, but rather consists of warming and cooling cycles at intervals of several decades. Nonetheless, the long term trend says there is a net global warming.
Corresponding with this warming, the alpine glaciers have been retreating, sea levels have risen, and climatic zones are shifting. Particularly the 1980s and 1990s were experienced to be the warmest decades on record. The 10 warmest years in global meteorological history have all occurred in the past 15 years and the 20th century has been the warmest globally in the last 600 years.

1.7. What will happen if the climate changes?

The climate change will have far-reaching and unpredictable environmental, social and economic consequences.

Increasing temperatures will lead to changes in weather, such as wind patterns, the precipitation, and the severe weather events.

The global sea level will rise due to melting of glaciers and polar ice caps.
Rising sea levels will submerge the low lying coastal regions through flooding and erosion. Many plant and animal species die as they cannot adjust quickly due to these changes. Harsh weather conditions, such as heat waves and droughts, can also happen more often and more severely.

Climate change could also affect health and well-being. Many larger cities could experience a significant rise in the number of very hot days. Air pollution problems would increase, placing children, the elderly and people suffering from respiratory problems at greatest risk of health effects. Increases in molds and pollens due to warmer temperatures could also cause respiratory problems such as asthma for some people.

1.8. What is being done around the world?

As the climate change affects the entire globe, developed and developing countries are working together to find solutions to prevent the climate change. In June 1992, the United Nations Framework Convention on Climate Change (UNFCC) was signed by 154 countries that agreed to stabilize the amount of greenhouse gases in the atmosphere at levels that won't cause harm. In December 1997, in Kyoto, Japan, Canada and 160 industrialized nations committed to reduce their greenhouse gas emissions, as part of an international agreement on climate change called the Kyoto Protocol.

1.9. What else can we do with regard to climate change?

As our climate is changing due to the existing rise of greenhouse gases in the atmosphere, we must be prepared to adapt to these changes. Thus as climate change in the coming decades is inevitable, planning must start now on adapting our economy and society to these changes.

Adaptation involves taking action to minimize the negative impacts of climate change and taking advantage of new opportunities that may arise. The types of adaptation measures taken will depend on the impact of climate change on particular regions and economic sectors. Increasing the capacity of adaptation will reduce the vulnerability to the effects of climate change. By start planning our adaptive responses now, we may help to lessen some of the environmental, economic and social costs of climate change.

2. The Earth's Past Climate history:

Throughout much of the earth's history, long before humanity came onto this world, the global climate was much warmer than now, with the global mean temperature perhaps between 8°C and 15°C warmer than it is today. During most of this time, the Polar Regions were free of ice. Later these warm conditions were interrupted by several periods of glaciation. Geologic evidence suggests that one glacial

period occurred about 700 million years ago (m.y.a.) and another about 300 m.y.a. The most recent one—the *Pleistocene epoch* or, simply, the **Ice Age**—began about 2 m.y.a.

Let's summarize the climatic conditions that led up to the Pleistocene. About 65 m.y.a., the earth was warmer than it is now; polar ice caps did not exist. Beginning about 55 m.y.a., the earth entered a long cooling trend. After millions of years, polar ice appeared. As average temperatures continued to lower, the ice grew thicker, and by about 10 m.y.a. a deep blanket of ice covered the Antarctic. Meanwhile, snow and ice began to accumulate in high mountain valleys of the Northern Hemisphere, and alpine, or valley, glaciers soon appeared. About 2 m.y.a., continental glaciers appeared in the Northern Hemisphere, marking the beginning of the Pleistocene epoch. The Pleistocene, however, was not a period of continuous glaciation but a time when glaciers alternately advanced and retreated (melted back) over large portions of North America and Europe. Between the glacial advances were warmer periods called **interglacial periods,** which lasted for 10,000 years or more.

The most recent North American glaciers reached their maximum thickness and extent about 18,000– 22,000 years ago (y.a.). At that time, the sea level was perhaps 120 m lower than it is now. The lower sea level exposed vast areas of land, such as the *Bering land bridge* (a strip of land that connected Siberia to Alaska), which allowed human and animal migration from Asia to North America.

The ice began to retreat about 14,000 years ago as surface temperatures slowly raised (Fig. 1). Then, about 11,000 years ago, the average temperature suddenly dropped, and northeastern North America and northern Europe reverted back to glacial conditions. About 1000 years later, the cold spell (known as the **Younger-Dryas**, this exceptionally cold spell is named after the *Dryas,* an arctic flower) ended abruptly, and by 8000 y.a. the continental ice sheets over North America were gone. From about 6000–5000 years ago, the climate was probably 1°C warmer than at present. This time frame represents the warmest of the current interglacial period, or *Holocene epoch*. For this reason, the warm spell is referred to as the *mid- Holocene maximum* and, because this warm period favored the development of plants, it is also known as the *climatic optimum*. About 5000 years ago, a cooling trend set in, during which extensive alpine glaciers returned, but not continental ice sheets.

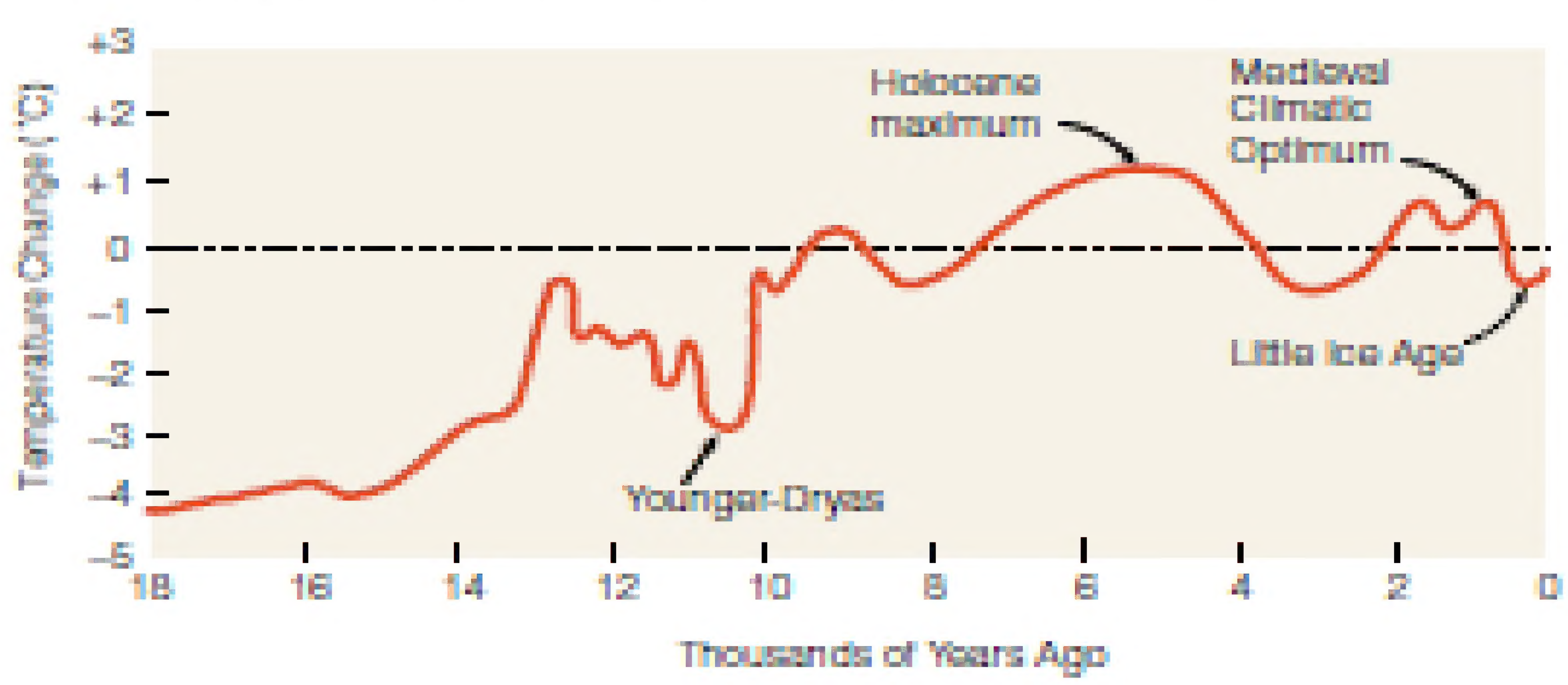

Fig.1. The average air temperature variations for the past 18,000 years

2.1. Climate change during the last 1000 years:

Figure 2a shows how the average surface air temperature changed in the Northern Hemisphere during the last 1000 years. Note that about 1000 years ago, the Northern Hemisphere was slightly cooler than the average (where average represents the average temperature from 1961 to 1990). However, certain regions in the Northern Hemisphere were warmer than others. Note in Fig.2a that the temperature curve shows a relatively warm period during the 11th to the 14th centuries — relatively warm, but still cooler than the 20th century.

During this time, the relatively mild climate of Western Europe began to show large variations. For several hundred years the climate grew stormy. Both great floods and great droughts occurred.

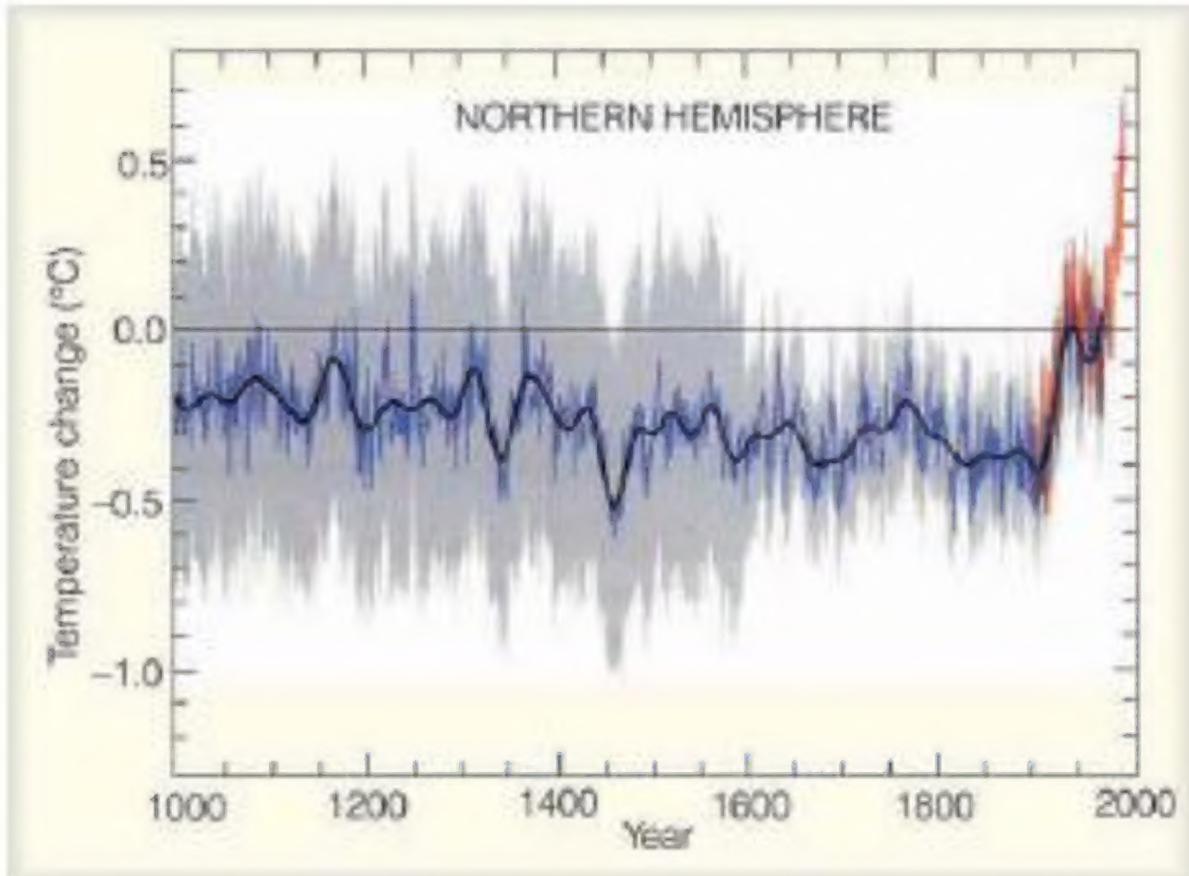

Fig.2a. The average temperature variation over the Northern Hemisphere for the last 1000 years relative to 1961 to 1990 average (zero line).

About 1000 y.a., according to Fig.2b, though the Northern Hemisphere was relatively warm and dry, compared to today it is less warm. It was during this warm, tranquil period of several hundred years (known as the *medieval climatic optimum*) that the Vikings colonized Iceland and Greenland. Sometime around A.D. 1200, the mild climate of Western Europe began to show extreme variations of cooling (Fig. 2b). However, starting in the middle of 1550s, the average temperature began to drop. This cooling trend (which continued for almost 300 years) is known as the **Little Ice Age.** During this time, the global mean temperature dropped by about 0.5°C, which allowed alpine glaciers to increase in size and advance down river canyons. During these colder times, one particular year stands out: 1816. In Europe that year, bad weather contributed to a poor wheat crop, and famine spread across the land. This year has come to be known as "the year without a summer". This unusually cold summer was followed by a bitterly cold winter.

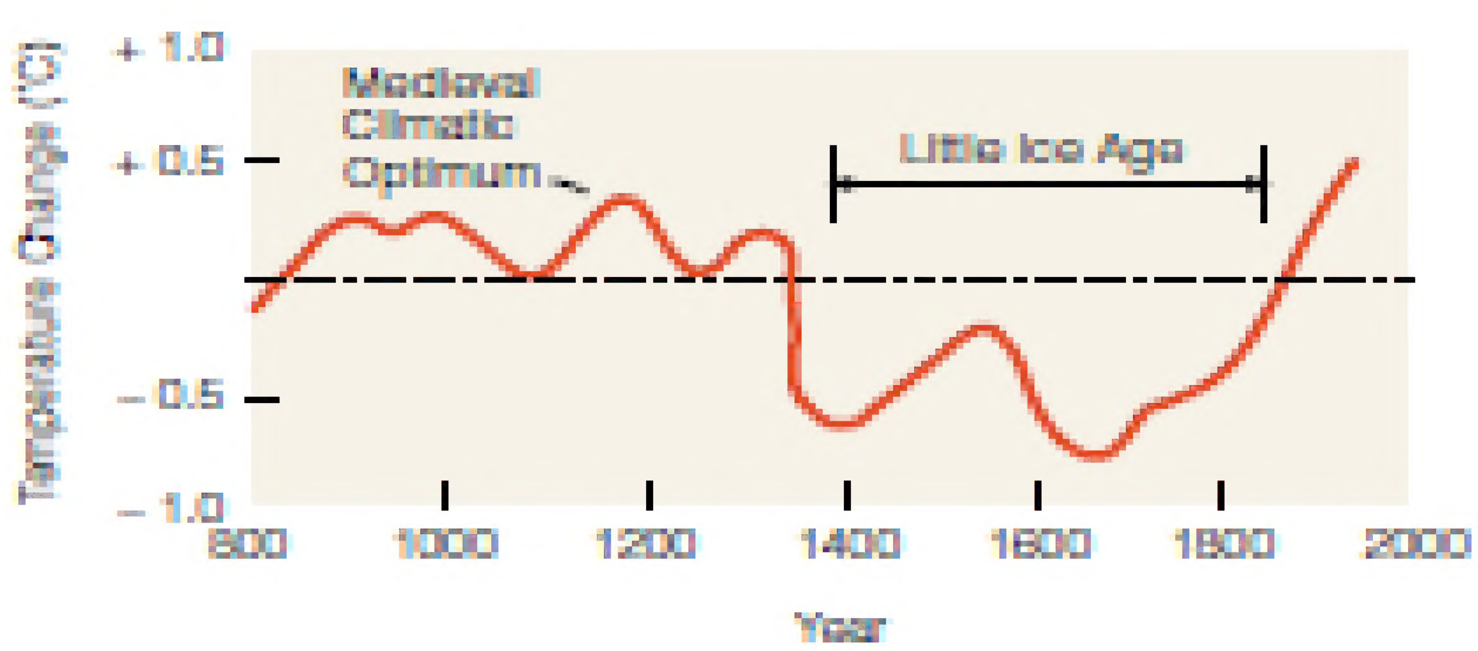

Fig.2b. The average temperature variations of eastern Europe during the last 1200 years.

2.2. Temperature trend during the past 100-plus years

In the early 1900s, the average global surface temperature began to rise (Fig.3). Note that, from about 1900 to 1945, the average temperature rose nearly 0.5°C. Following the warmer period, the earth began to cool slightly over the next 25 years or so. In the late 1960s and 1970s, the cooling trend ended over most of the Northern Hemisphere.

In the mid-1970s, a warming trend sets in and that continued until the twenty-first century. In fact, over the Northern Hemisphere, the decade of the 1990s was the warmest of the 20^{th} century, with 1998 and 2005 being the warmest years in over
1000 years.

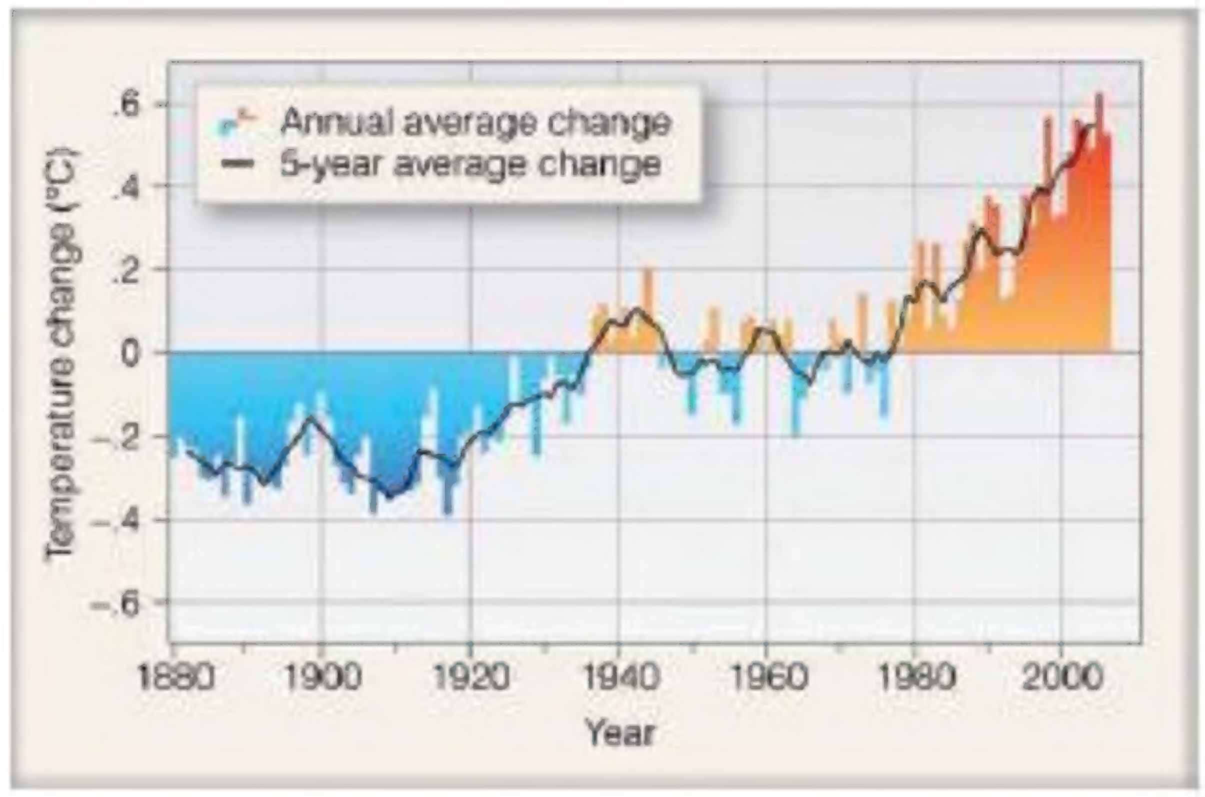

Fig.3. The red and blue bars represent the annual average temperature variations over the globe from 1880 to 2006. Tempertature changes are compared to the average surface temperature from 1951-1980. The dark solid line shows the five year average temperature change. The zero line represents the average surface air temperature from 1951 to 1980.

We can see in Fig. 3 that over the last hundred years or so from 1910 to 2010, the earth's surface has warmed by about 0.7°C. A point to be noted here is that a global increase in temperature of 0.7°C may seem to be very small, but in Fig. 1 we can see that global temperatures have varied not more than 1.5°C during the past 10,000 years. So when compared to that increase (over thousands of years) this increase (over 100 years) of 0.7°C becomes significant and very high.

These results thus reveal that during the past century the earth has been in a warming trend. Most climate scientists believe that at least part of this warming is due to an enhanced greenhouse effect caused by increasing levels of greenhouse gases, such as CO_2.

3. Causes of Climate Change

Although theories about the causes of climate change are many, they can be mainly expressed into four broad categories. They are (1) astronomical variations in Earth's orbit; (2) changes in atmospheric composition; (3) changes in oceanic circulation; and (4) changes in landmasses that affect albedo and oceanic circulation.

3.1. Orbital Variations

Astronomers have detected slow changes in Earth's orbit that affect the distance between the sun and Earth as well as the deviation of Earth's axis on the plane of the ecliptic (fig.4).

These orbital cycles produce regular changes in the amount of solar energy that reaches Earth. The longest is known as the **eccentricity cycle,** which is a 100,000-year variation in the shape of Earth's orbit around the sun. In simple terms, Earth's orbit changes from an ellipse (oval), to a more circular orbit, and then back, affecting Earth–sun distance (Fig.4a).

A second cycle, termed the **obliquity cycle,** represents a 41,000-year variation in the tilt of Earth's axis from a maximum 24.5° to a minimum of 22.0° and then back. The more Earth is tilted, the greater is the seasonality at middle and high latitudes (Fig.4b).

Finally, a **precession cycle** has been recognized with a periodicity of 21,000 years. As the earth rotates on its axis, it wobbles like a spinning top. This wobble, known as the **precession** of the earth's axis, occurs in a cycle of about 21,000 years. Presently, the earth is closer to the sun in January and farther away in July. Due to precession,the reverse will be true in about 10,500 years. The precession cycle determines the time of year that perihelion occurs. Today, Earth is closest to the sun on January 3 and, as a result, receives about 3.5% greater insolation than the average in January. When aphelion occurs on January 3 in about 10,500 years, the Northern Hemisphere winters should be somewhat colder (Fig. 4C &d).

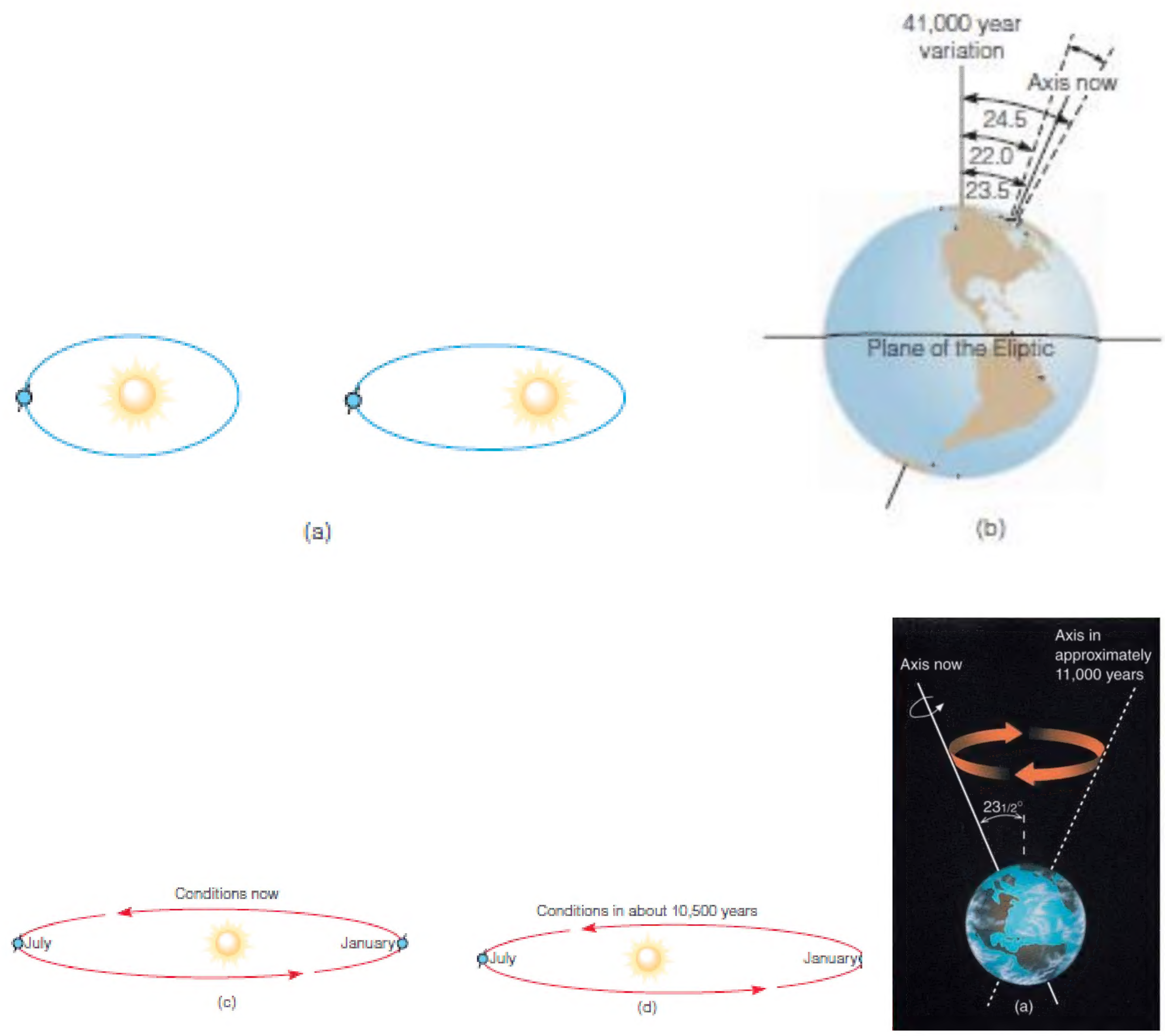

Fig.4. Milankovitch calculated the periodicities for (a) eccentricity, (b) obliquity and (C)&(d) precession
(a) eccentricity: For the earth's orbit to stretch from nearly a circular(left) to an elliptical orbit (right) and back again takes nearly 100,000 years.
(b) obliquity: The earth currently revolves around the sun while tilted on its axis by an angle of 23.5°. During a period of 41,000 years, this angle of tilt ranges from about 22° to 24.5.
(C)&(d) precession: (c) Presently the earth is closer to the sun in January, when the Northern Hemisphere experiences winter.(d) In about 10,500 years, due to precession, the earth will be closer to the sun in July, when the Northern Hemisphere experiences summer

These cycles operate collectively, and the combined effect of the three cycles were calculated by the mathematician Milutin Milankovitch and showed how these changes in Earth's orbit would affect insolation.

The Milankovitch theory indicates that the warm Holocene interglacial will soon end and that Earth is destined to experience full glacial conditions (glacial ice possibly as far south as the Ohio and Missouri Rivers) in about 20,000 years.

3.2. Changes in Earth's Atmosphere

Many theories attributes that the climate changes are related to the changes in the variations in the atmospheric dust levels. These atmospheric dust levels are caused due to volcanic activity and green house gas emissions.

3.2. 1. Volcanic Activity

The climatic cooling effect caused by volcanic activity is well known. As the volcanic ash goes into the stratosphere masks the sun light causing a cooling effect on the earth's surface.

All of the coldest years on record over the past two centuries have occurred in the year following a major eruption of volcanoes. For example, following the massive eruption of Tambora (in Indonesia) in 1815, 1816 was known as "the year without a summer." Chilling frosts in July ruined crops in New England and Europe, resulting in famines. Several decades later, following the massive eruption of Krakatoa (also in Indonesia) in 1883, temperatures decreased significantly during 1884. Although no 20th-century eruptions have approached the magnitude of these two, the 1991 eruption of Mt. Pinatubo (in the Philippines) produced a substantial respite of cool conditions in an otherwise continuous series of record of warm years (Fig.5).

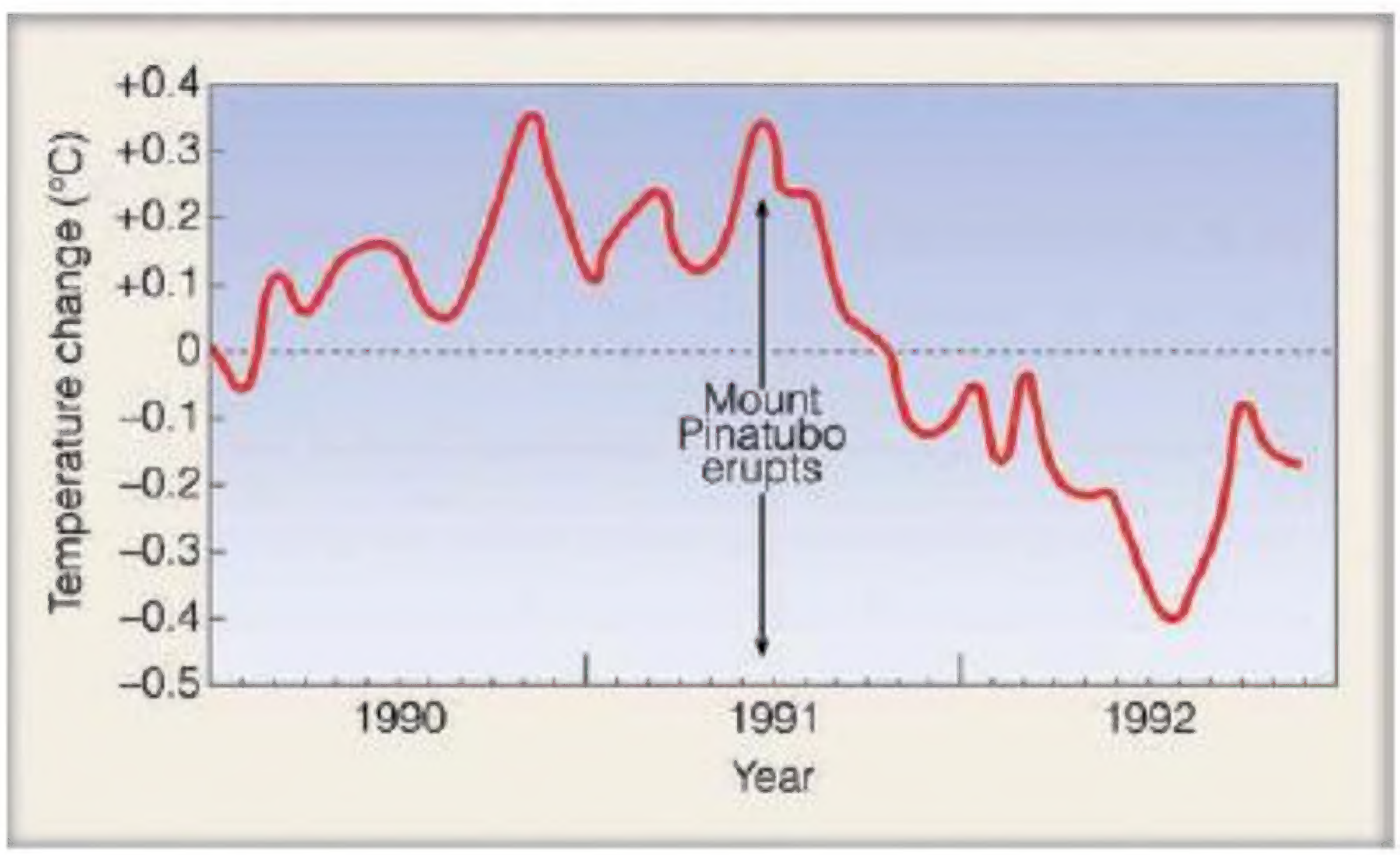

FIGURE 5. Changes in average global air temperature from 1990 to 1992. After the eruption of Mount Pinatubo in June, 1991, the average global temperature by July, 1992, decreased by almost 0.5°C from the 1981 to 1990 average (dashed line).

3.2.2. Atmospheric Gases

Another phenomenon closely related to the average global temperatures is the composition of atmospheric gases. It is known that carbon dioxide (CO_2) acts as a "greenhouse gas."That is CO_2 is transparent to incoming shortwave radiation and blocks outgoing longwave radiation, similar to the effect of the glass panes in a greenhouse or automobile on a sunny day which is called green house effect. Thus, as the levels of greenhouse gases rise, the amount of heat trapped in the lower atmosphere also increases. The present level of approximately 379 parts per million of CO_2 is already higher than at any time in the past million years which enormously increases the temperature of the earth as shown in Fig.6. During the industrial era, CO_2 abundance rose roughly exponentially to 367ppm (0.0367%) in 1999 and to 379ppm (0.0379%) by 2005 (Fig.6).

It may be interesting to note that a small atmospheric air was trapped in the air bubbles when the glacial ice of Antarctica and Greenland Was formed. One of the important discoveries of the ice-core projects is that prehistoric atmospheric CO_2 levels increased during interglacial periods and decreased during major glacial advances.

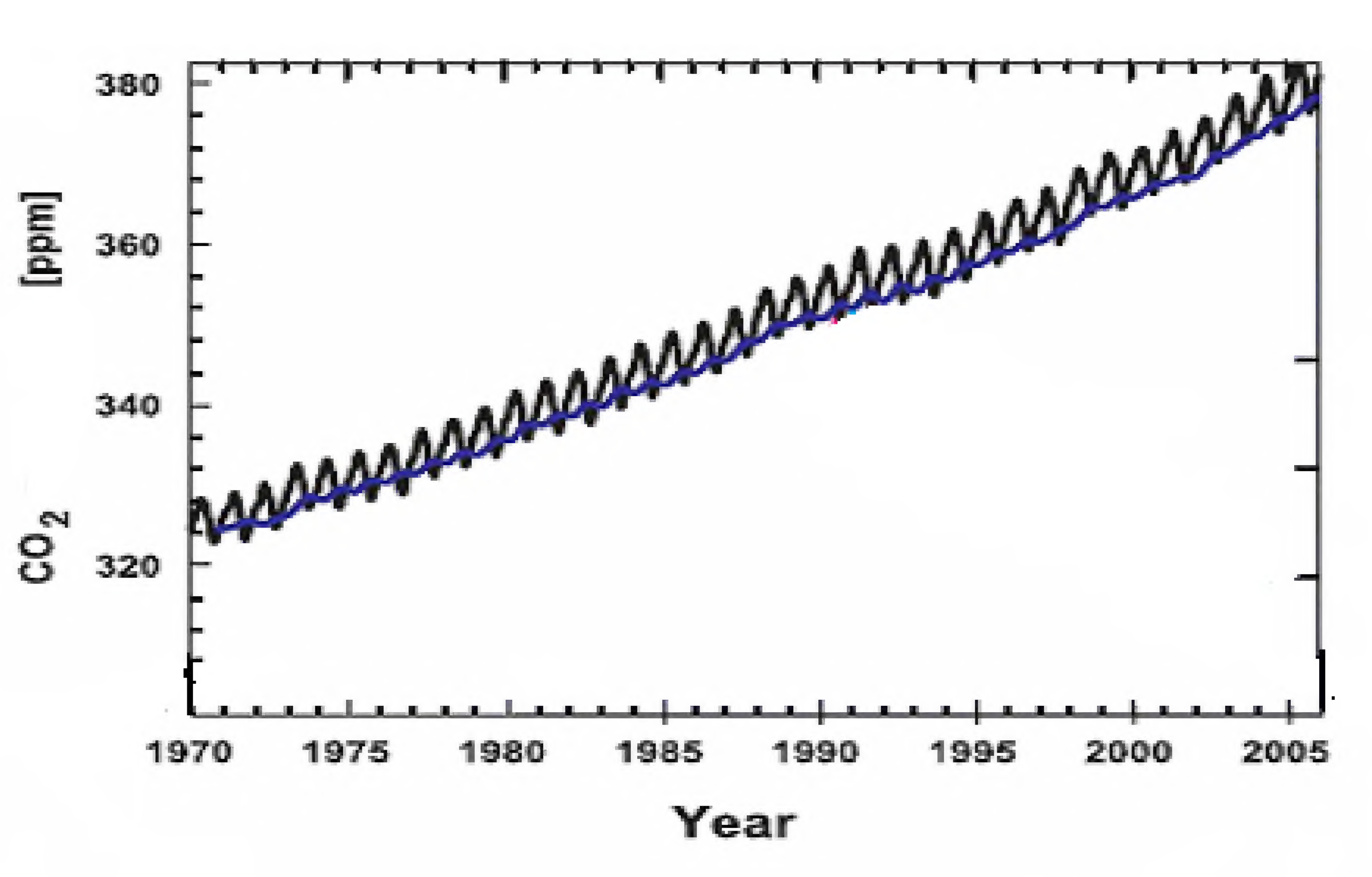

Fig.6. Increasing trend of CO_2 since the industrialization began

Another important greenhouse gas contributes for warming is methane (CH4)which is over 20 times more effective than CO_2 but is considered less important because the atmospheric concentrations and the length of time the molecules of gas remain in the atmosphere (residence time) is much smaller. Emissions from Garbage dump and termite mounds produce substantial quantities of CH4. Another important source of atmospheric methane may come from the tundra and the deep sea regions. The warming of the tundra or ocean water releases large amounts of methane. The resulting positive feedback cycle of warming could be enormous.

Other greenhouse gases include CFCs (chlorofluorocarbons) and N_2O (nitrous oxide). The relative greenhouse contribution of common greenhouse gases and their average residence times in the atmosphere are presented in Figure 7.

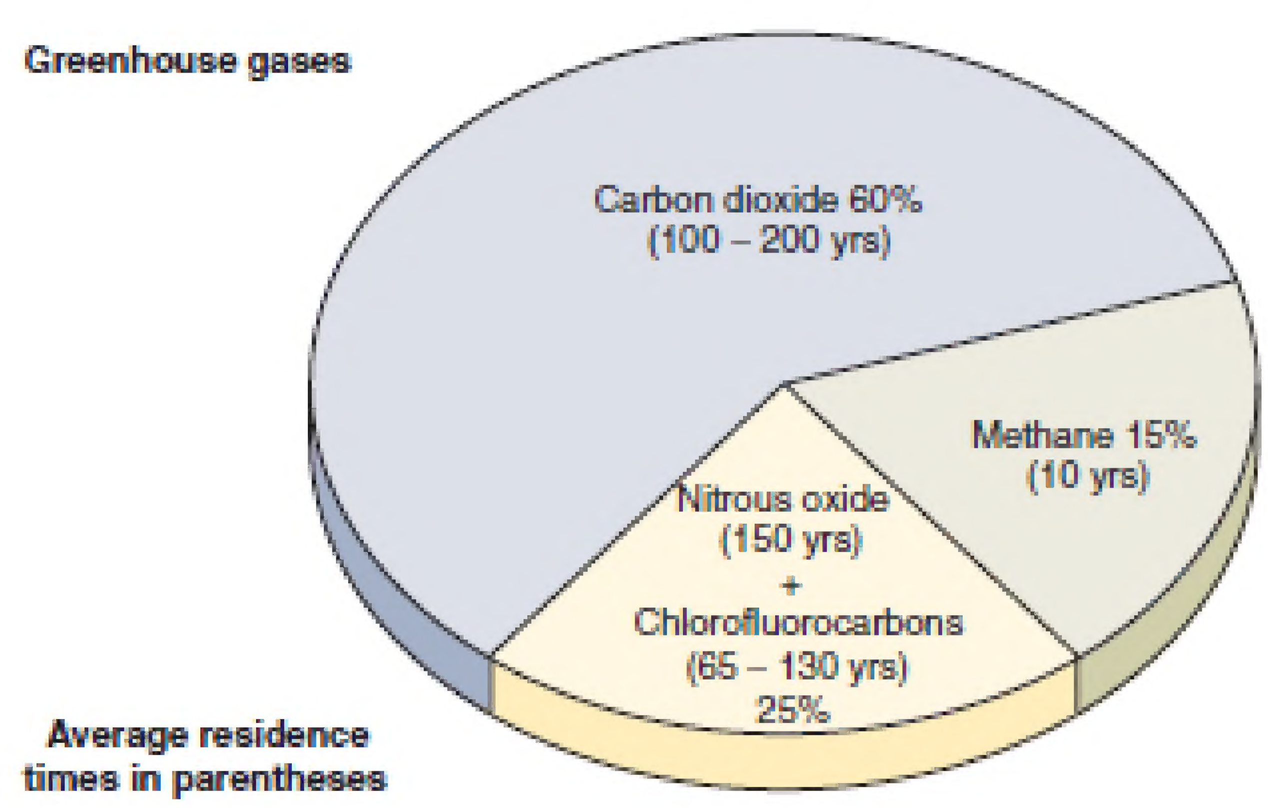

Fig.7. Gases other than carbon dioxide, released to the atmosphere by human activity contribute approximately 25% to the green house effect. The figures in parenthesis indicate the average number of years that the different gases remain in the atmosphere and contribute to temperature change.

3.3. Changes in the Ocean

Oceans cover over 70% of Earth's surface. Their enormous volume and high heat capacity make the oceans the single largest buffer against changes in Earth's climate. Whenever changes occur in oceanic temperatures, chemistry, and circulation, significant changes in global climate are happening.

Surface ocean currents are driven mostly by winds. However, a much slower circulation in the sea bottom (called abyssal circulation) as shown in Fig. 8, moves large volumes of water between one ocean to the other ocean. A major driving force of this deep sea circulation appears to be differences in water buoyancy caused by differences in salinity (salt content).

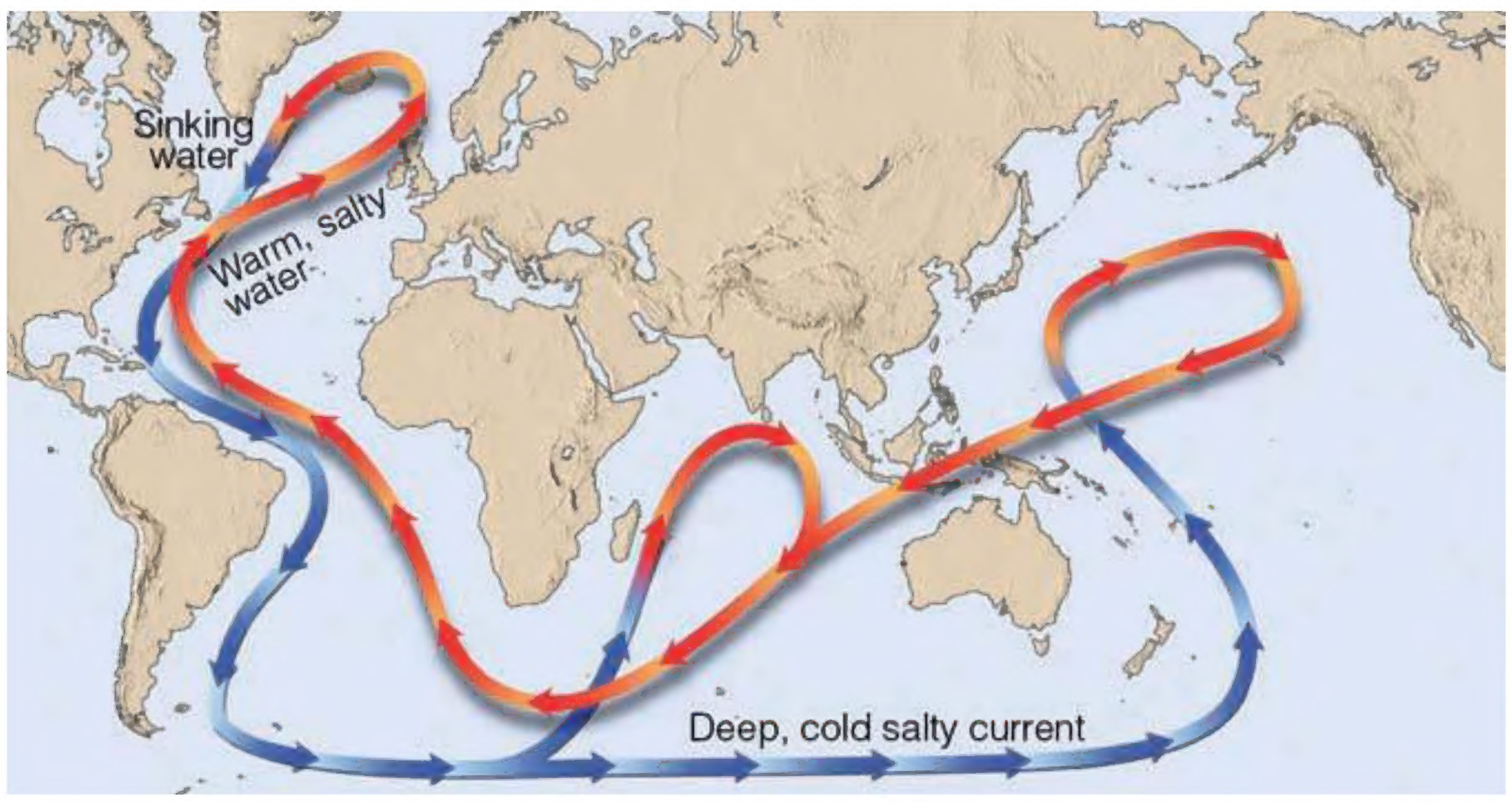

Fig.8.The abyssal circulation (The ocean conveyor belt). In the North Atlantic, cold, salty water sinks, drawing warm water northward from lower latitudes. The warm water provides warmth and moisture for the air above, which is then swept into northern Europe by westerly winds that keep the climate of that region milder than one would normally expect. When the conveyor belt stops, winters apparently turn much colder over northern Europe.

Where surface evaporation is more, the rising salinity content causes the seawater density to increase, inducing subsidence. On the other hand, when major influxes of freshwater flow from adjacent continents or melting icebergs, the salinity is reduced, thereby increasing the buoyancy of the water. When the surface water is more buoyant, deep-water circulation slows.

In many cases, the freshwater influx is immediately followed by a major flow of warm surface waters into the North Atlantic, causing an abrupt warming of the Northern Hemisphere.

Subsurface ocean currents are also affected by water temperature. Extremely cold Arctic and Antarctic waters are quite dense and tend to subside, whereas tropical water is warmer and may tend to rise. Therefore,the circulation caused due to temperature and salinity taken together (called thermohaline circulation) bring about rather complex subsurface flows deep within the ocean basins.

In modern times, short-term changes in Pacific circulation are primarily responsible for El Nino and La Nina events. The onset of El Nino/Southern Oscillation (ENSO) climatic events is both rapid and global in extent, and it is widely believed that changes in oceanic circulation may be responsible for similar rapid climate changes during the last 2.4 million years.

3.4. Changes in Landmasses

The final category of climate change theories involves changes in Earth's surface due to continental drift (plate tectonics).

Plate tectonics says Earth is considered into three spheres. Outer most sphere is called crust. Below the crust called mantle and the inner most sphere is core. While the crust is very light, the mantle and core are heavy containing iron and nickel mixture with hotter temperatures. The crust contains plates with continents (Fig.9) and float in the molten mantle. As it is floating it is subjected to motion

due to eddy currents in the mantle. The rate of motion is extremely slow, only a few centimeters per year. As the continents move the climates change.

According to plate tectonics, the now existing continents were at one time joined together in a single huge continent, which broke apart. Its pieces slowly moved across the face of the earth, thus changing the distribution of continents and ocean basins, as illustrated in Fig. 10.

Some scientists speculate that climatic change, taking place over millions of years, can be related to the rate at which the plates move and, hence, related to the amount of CO_2 in the air. For example, during the times of rapid spreading, an increase in volcanic activity releases large quantities of CO_2 into the atmosphere, which enhances the atmospheric greenhouse effect, causing global temperatures to rise.

Millions of years later, when spreading rates decrease, less volcanic activity means less CO_2 is spewed into the atmosphere. A reduction in CO_2 levels weakens the greenhouse effect, which, in turn, causes global temperatures to drop. The accumulation of ice and snow over portions of the continents may promote additional cooling by reflecting more sunlight back to space.

A chain of volcanic mountains forming above a subduction zone may disrupt the air flow over them. In the same way, mountain building that occurs when two continental plates collide (like the formation of the Himalayan mountains and Tibetan highlands) can have a marked influence on global circulation patterns and, hence, on the climate of an entire hemisphere.

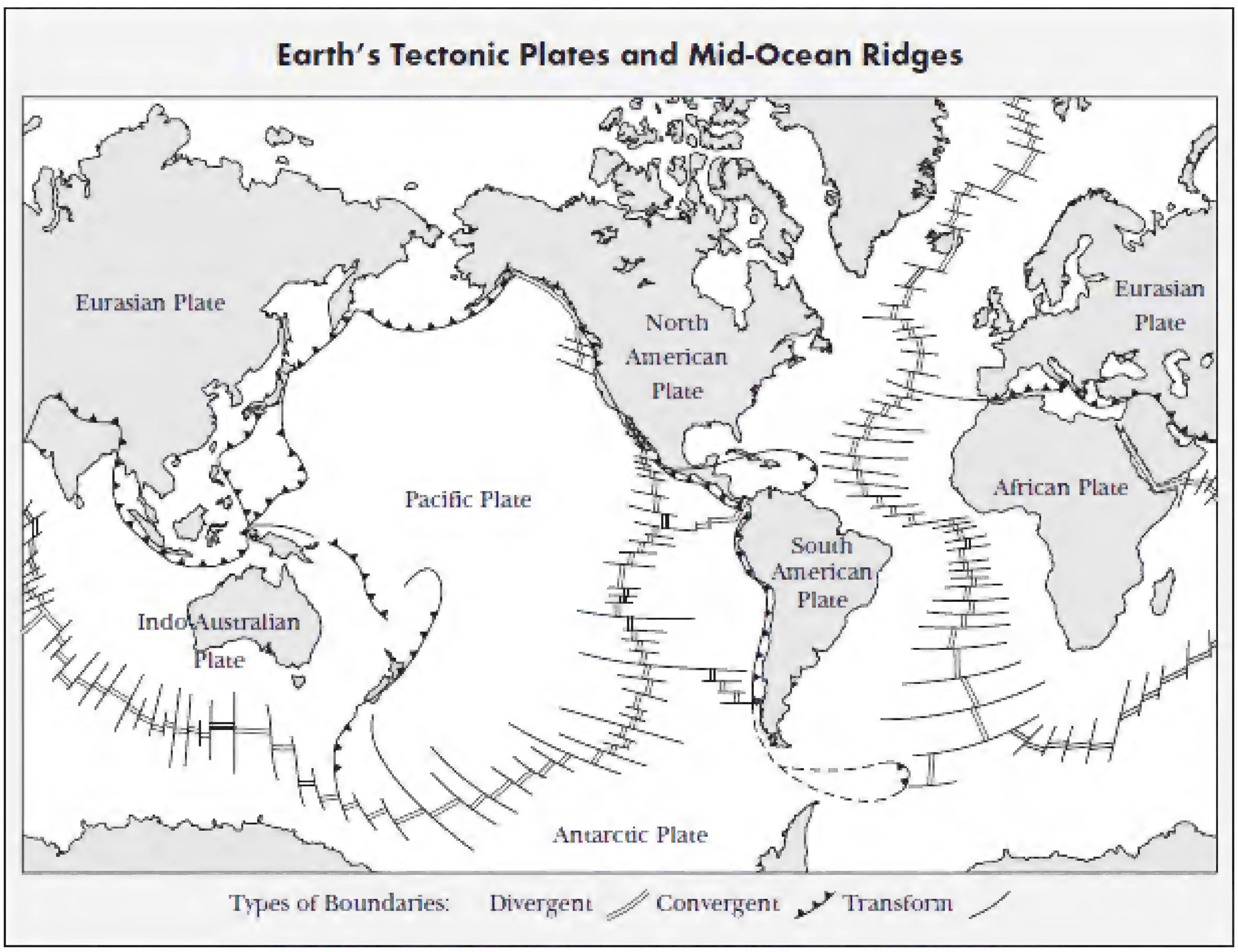

Fig. 9.Earth's tectonic Plates and associated continents. The rift zone is shown by boundaries from which the plates move apart.

Fig. 10. Geographical distribution of (a) landmasses about 150 million years ago, and (b) today. Arrows show the relative direction of continental movement.

4. Radiative forcing:

Radiative forcing is defined as "the change in net irradiance at the tropopause after allowing stratospheric temperatures to readjust to radiative equilibrium. The global mean radiative forcing (ΔF) can be simply related to the equilibrium global mean surface temperature change (ΔT) by the formula $(\Delta T) = \lambda (\Delta F)$ where λ is the climate sensitivity parameter.

The concept of Radiative forcing :

It is the incoming energy minus the outgoing energy in response to a factor that changes the energy balance.For example, the radiative forcing of the GHG, CO_2 is 1.66 w m^{-2} (Table 2.1). This means the CO_2 in the atmosphere has reduced the outgoing radiation by 1.66 w m^{-2} compared to what was present during pre-industrial period (1750). The importance of this concept is to quantify and assess the relative importance of the various factors that shift the energy balance.

Major radiative forcings are Greenhouse gases, Aerosols**,** Land use changes, Solar and volcanic forcings. The contribution of different green house gases for radiative forcing is given in Fig.11.

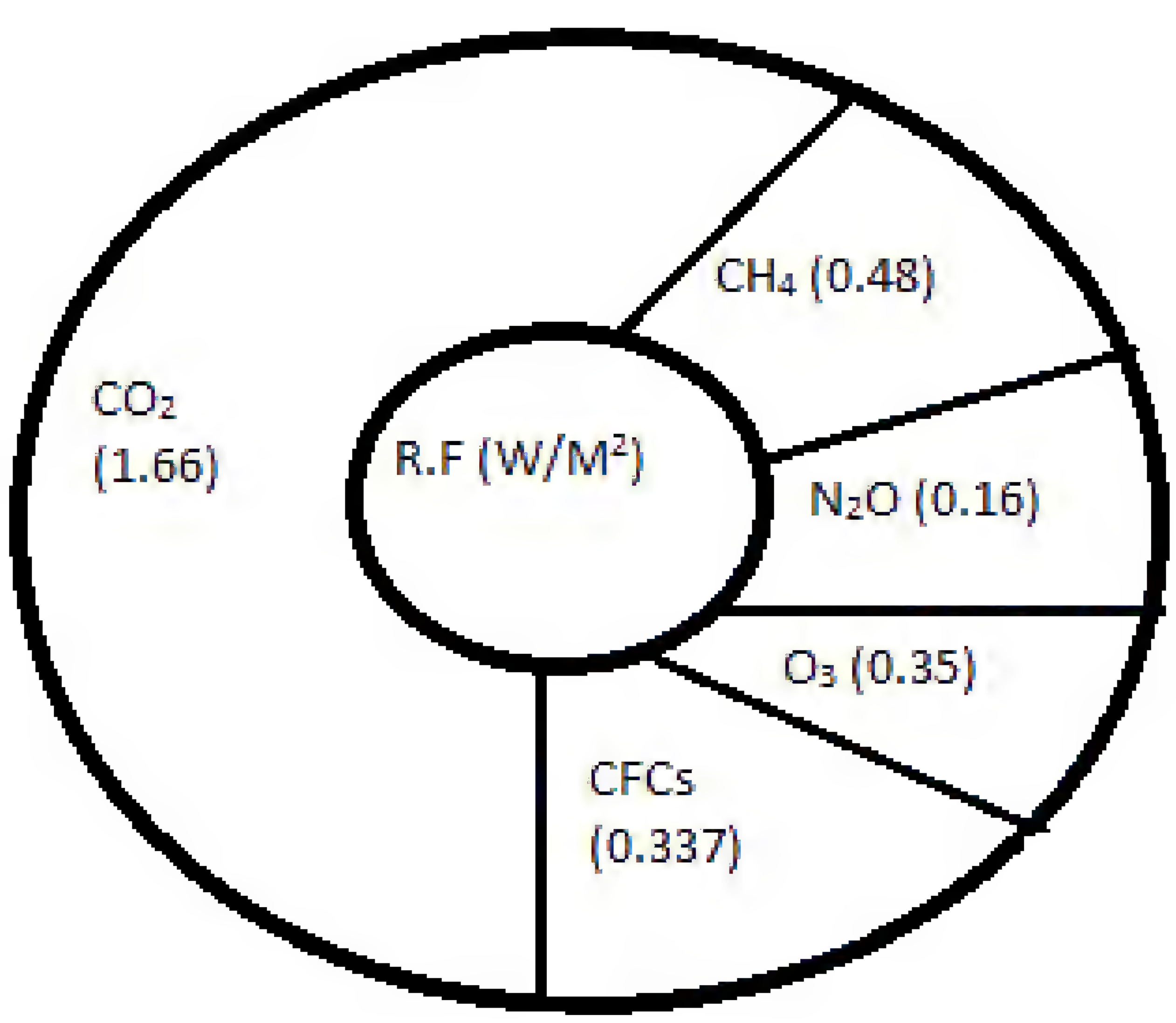

Fig.11. Contribution of different GHGs for Radiative Forcing (watts/m^2).

Today most of the excess CO_2 comes from fossil fuel burning (automobiles, cooking gas, thermal power plants etc.), cement production, land use deforestation etc. The methane (CH_4) is the second most GHG (Fig.11) in radiative forcing. The primary natural source of CH_4 is decaying vegetation in soils and wetlands. Major sources of anthropogenic causes include agriculture, landfills and natural gas emissions. The 8,00,000 year old record preserved in Antarctic ice shows that the CH_4 varied only between 400 to 700 ppb throughout the glacial and interglacial periods. But today it contains 1,775ppb in the atmosphere.

Of somewhat lesser importance is Nitrous Oxide (N_2O) which forms naturally in soils and the ocean. N_2O is also a byproduct of agriculture and fossil fuel combustion. So its concentration increased from pre-industrial level of about 270 ppb to present day concentration of 321 ppb.

Another set of GHGs are manufactured halocarbons. They include chlorofluorocarbons (CFCs) like CCl_3F and Hydrochlorofluorocarbons (HCFCs) for example, $CHCl\ F_2$). Although their presence in the atmosphere is small, we are very much worried about them due to their long residence times. Particularly they interact with stratospheric O_3 (see Fig.12) and contributes for Ozone hole as shown in the Fig.13.

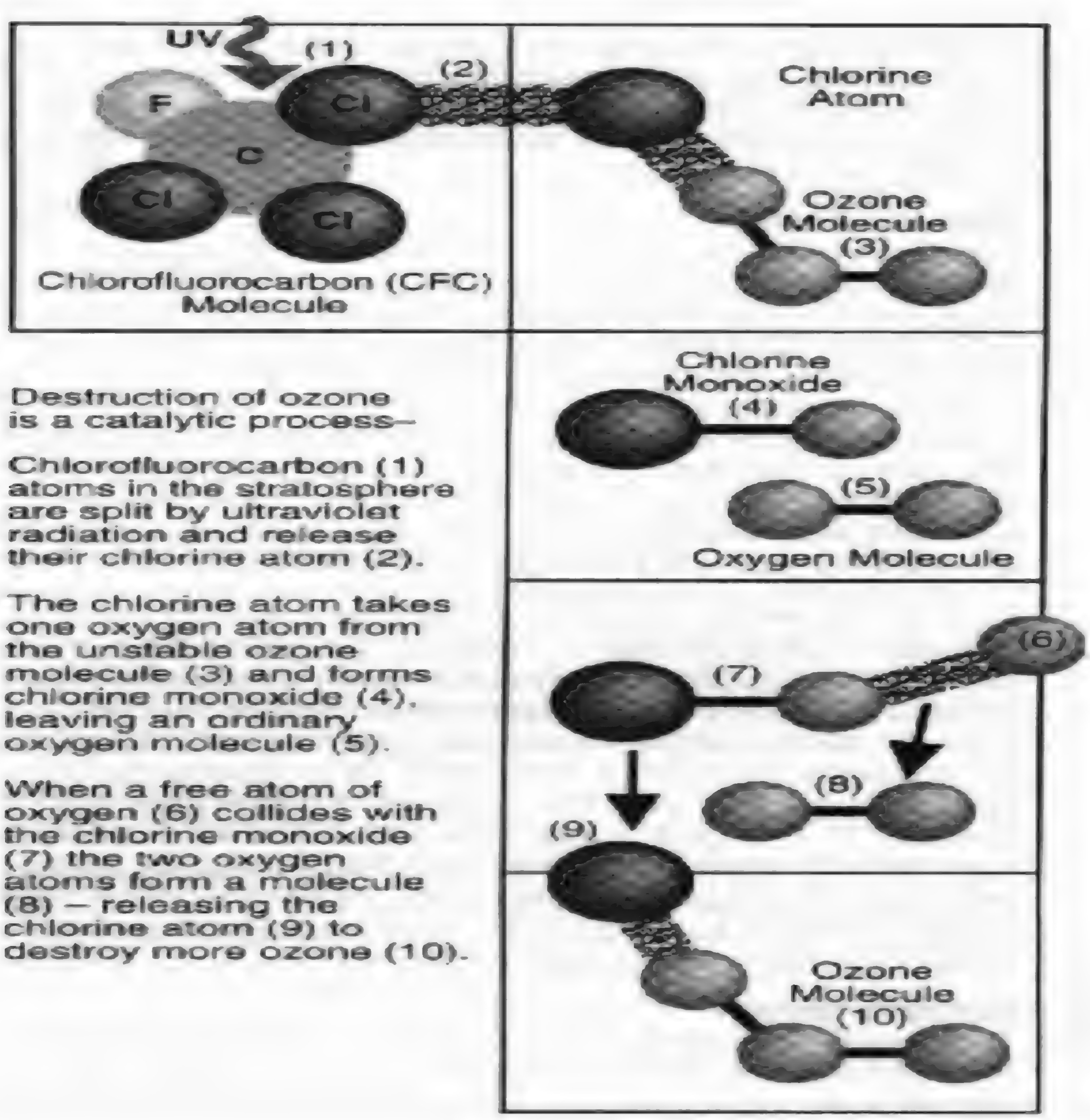

Fig.12. Reaction of CFCs with Ozone under UV radiation in stratosphere and topple the ozone balance.

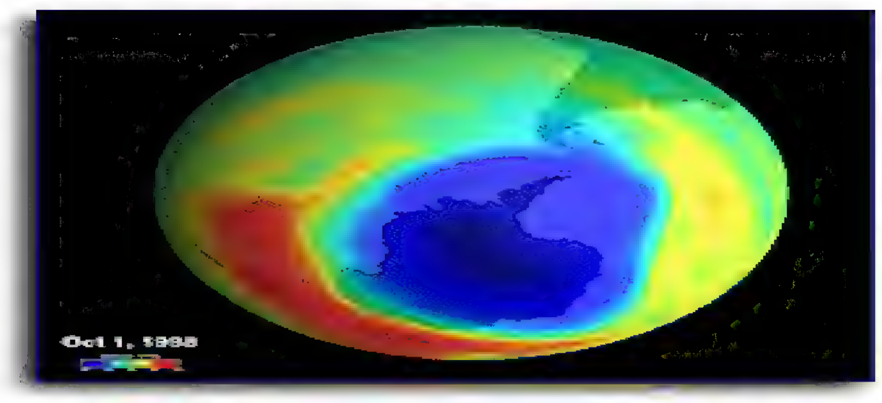

Fig.13. Due to toppling in ozone balance caused by CFCs, Ozone hole formed over Antarctica

4.1. Ozone Balance and imbalance:

The normal ozone balance in the presence of ultraviolet (UV) radiation is as below:

$$O_3 \xrightarrow{UV radiation} O_2 + O$$
$$O + O_2 \rightarrow O_3$$

But once the CFC s enters into this balance in stratosphere, the ozone imbalance causes like this:

$$O_3 \xrightarrow{UV radiation} O_2 + O$$
$$O + CFC \rightarrow CFCO$$
$$O_3 disappears$$

The stratospheric ozone changes are particularly large in Polar Regions, as the reactions responsible for the destruction of ozone in the presence of some chemical compounds (such as chlorofluorocarbons) are more efficient at low temperatures. The largest decrease is observed over the high latitudes of the Southern Hemisphere. There, the famous ozone hole (Fig.13), discovered in the mid 1980's, is a large region of the stratosphere where about half the ozone disappears in spring.

The main radiative forcings that have affected the Earth's climate can be grouped into different categories. This has classically been done to estimate both the anthropogenic and natural forcings compared to preindustrial conditions corresponding typically to 1750 (Fig. 14). Over the last 250 years, the changes in greenhouse gas concentrations have played a dominant role. The largest contribution comes from the modification of the atmospheric CO_2 concentration, with a radiative forcing of about 1.66 Wm^{-2} between 1750 and 2005(Table 2.1). However concentrations of CH_4, N_2O and the halocarbons also have to be taken into account because they rank number 2 and 3 after CO_2 with radiative forcings of 0.48 and 0.16 respectively.

CO_2, CH_4, N_2O and halocarbons are long-lived gases that remain in the atmosphere for decades if not centuries. Their geographical distribution is thus quite homogenous, with only small differences between the two hemispheres. Other greenhouse gases such as O_3 (ozone) have a shorter life. As a consequence, their concentration, and thus the associated radiative forcing, tends to be higher close to areas where there are produced and lower near areas where they are destroyed. The stratospheric

ozone has decreased since pre-industrial time, leading to a globally average radiative forcing of -0.05 Wm $^{-2}$. See the table 2.1 for details.

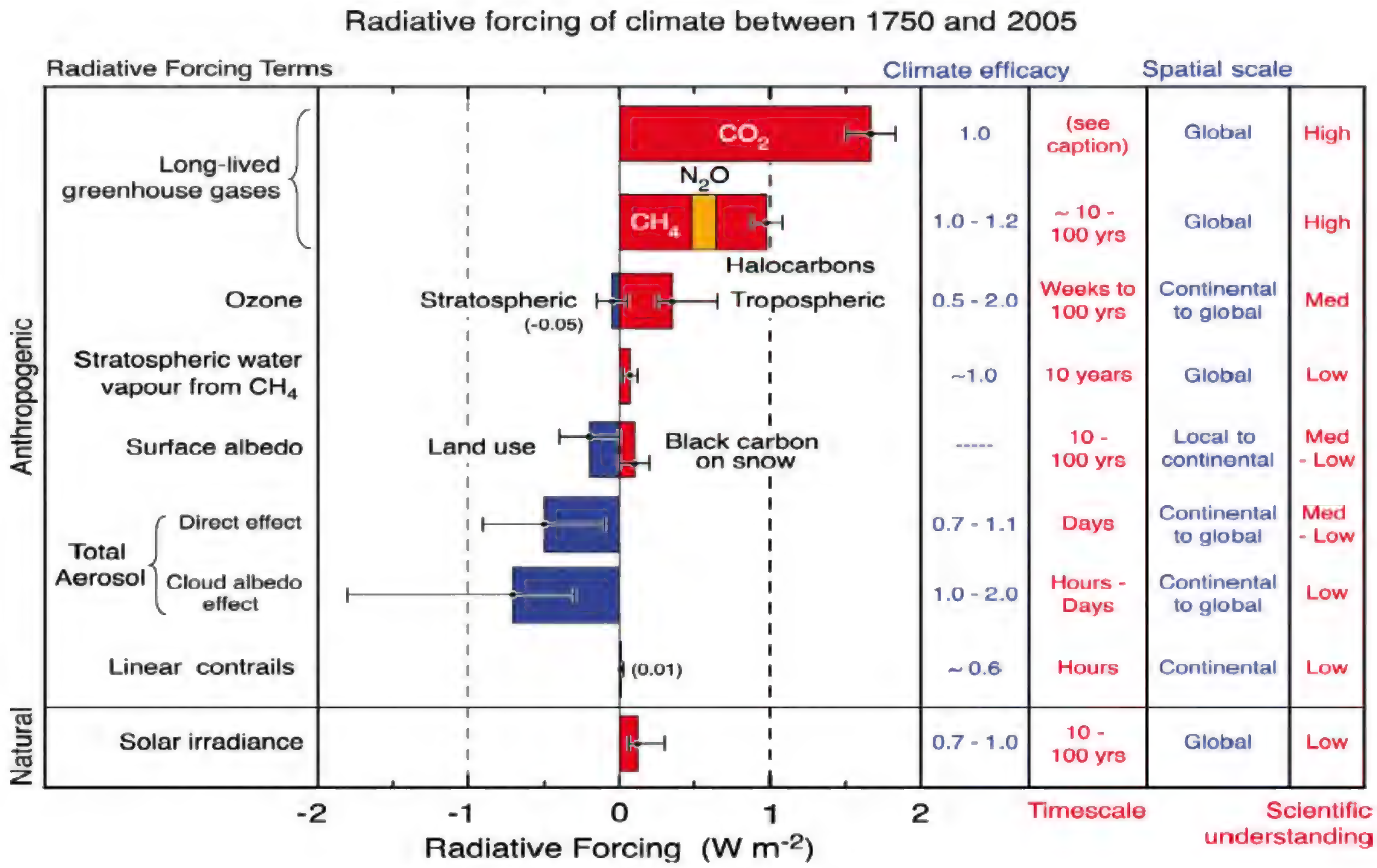

Figure 14: Global mean radiative forcings from various agents and mechanisms between 1750 and 2005. Time scales represent the length of time that a given radiative forcing term would persist in the atmosphere after the associated emissions and changes have ceased. No CO_2 time scale is given, as its removal from the atmosphere involves a range of processes that can span long time scales, and thus cannot be expressed accurately with a narrow range of lifetime values.

Table 2.1. *Present-day concentrations and RF for the measured LLGHGs. The changes since 1998 (the time of the TAR estimates) are also shown.*

	Concentrations[b] and their changes[c]		Radiative Forcing[d]	
Species[a]	2005	Change since 1998	2005 (W m^{-2})	Change since 1998 (%)
CO_2	379 ± 0.65 ppm	+13 ppm	1.66	+13
CH_4	1,774 ± 1.8 ppb	+11 ppb	0.48	-
N_2O	319 ± 0.12 ppb	+5 ppb	0.16	+11
	ppt	ppt		
CFC-11	251 ± 0.36	−13	0.063	−5
CFC-12	538 ± 0.18	+4	0.17	+1
CFC-113	79 ± 0.064	−4	0.024	−5
HCFC-22	169 ± 1.0	+38	0.033	+29
HCFC-141b	18 ± 0.068	+9	0.0025	+93
HCFC-142b	15 ± 0.13	+6	0.0031	+57
CH_3CCl_3	19 ± 0.47	−47	0.0011	−72
CCl_4	93 ± 0.17	−7	0.012	−7
HFC-125	3.7 ± 0.10[e]	+2.6[f]	0.0009	+234
HFC-134a	35 ± 0.73	+27	0.0055	+349
HFC-152a	3.9 ± 0.11[e]	+2.4[f]	0.0004	+151
HFC-23	18 ± 0.12[g,h]	+4	0.0033	+29
SF_6	5.6 ± 0.038[i]	+1.5	0.0029	+36
CF_4 (PFC-14)	74 ± 1.6[j]	-	0.0034	-
C_2F_6 (PFC-116)	2.9 ± 0.025[g,h]	+0.5	0.0008	+22
CFCs Total[k]			0.268	−1
HCFCs Total			0.039	+33
Montreal Gases			0.320	−1
Other Kyoto Gases (HFCs + PFCs + SF_6)			0.017	+69
Halocarbons			0.337	+1
Total LLGHGs			2.63	+9

Radiative Forcing is linked to other aspects of climate change:

The components of climate change process is shown in Fig.15. Human activities and natural processes cause direct and indirect changes in climate drivers. These changes result in specific Radiative Forcing changes, either +ve or –ve and cause some non initial Radiative effects such as changes in evaporation. Radiative Force & non initial Radiative effects lead to climate perturbations and responses. The coupling among biogeochemical processes leads to feedback from climate change to its drivers. The potential approaches to mitigate climate change by altering human activities (dashed line).

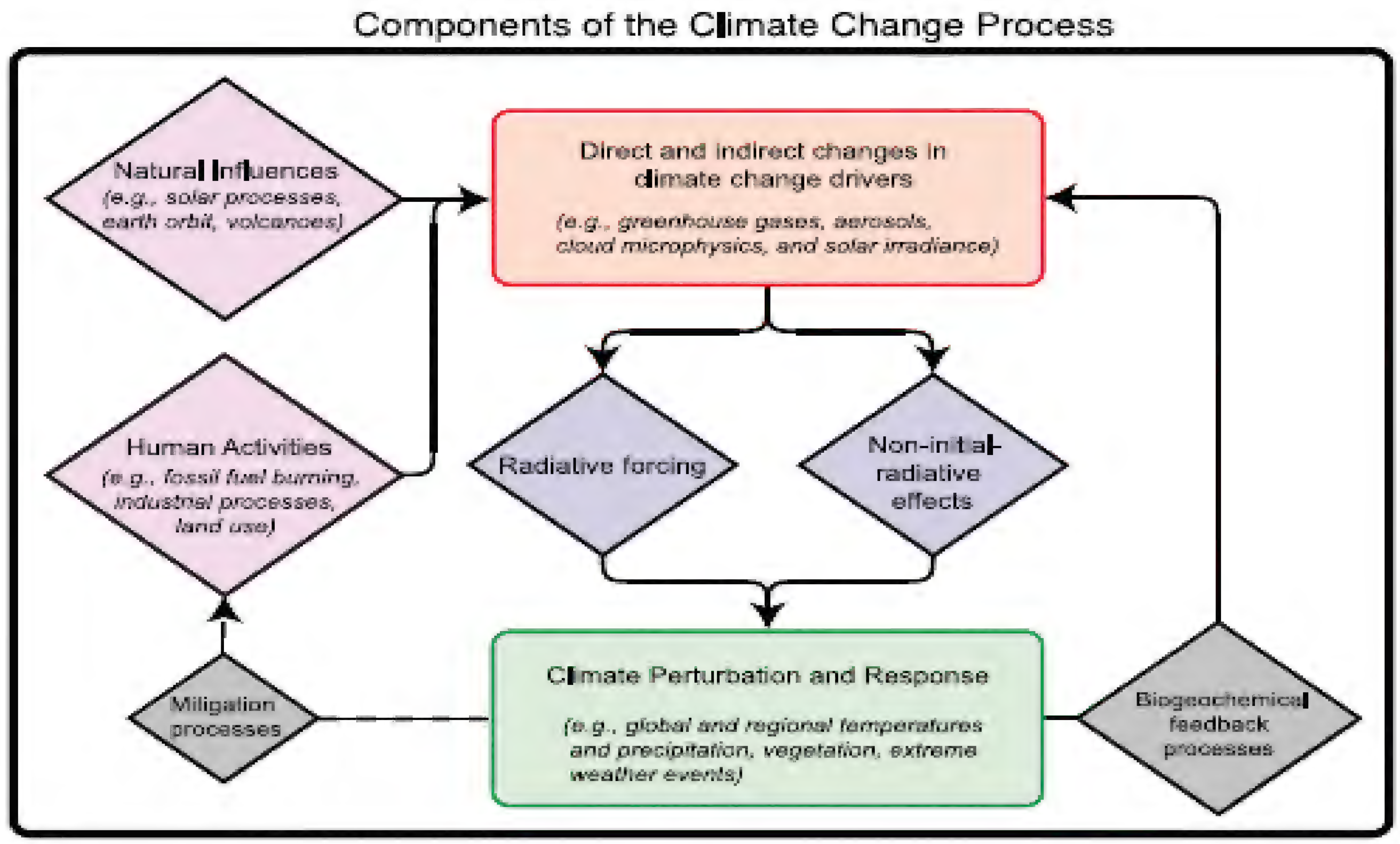

Fig. 15. RF linked to other aspects of climate change

5. Green House warming Potential

To compare the relative contributions of various trace gases to the green house effect it is convenient to define a green house warming potential (GWP). The GWP is defined as the mass of CO_2 that would need to be instantaneously injected into the atmosphere to produce an incremental increase in the greenhouse effect equivalent to that caused by the injection of 1 Kg of a specified gas, integrated over a specified time interval, taking into account the time dependent decay of the required gas as well as that of CO_2

In symbolic form it is written as

$$\text{GWP} = \frac{\int_0^T a_x c_x(t)dt}{\int_0^T a_{CO_2} c_{CO_2}(t)dt}$$

Where T is the specified time interval, a_x is the radiative efficiency of gas x ($wm^{-2}kg^{-1}$), c_x is the fraction of mass of gas x injected into the atmosphere at time t=0 such that it remains in the atmosphere upto time t=t and a_{CO2} and C_{CO2} are the corresponding quantities of CO_2. The numerator is called the Absolute Green House Warming Potential (AGWP).

6. Global warming Potential:

$$GWP_i \equiv \frac{\int_0^{TH} RF_i(t)\,dt}{\int_0^{TH} RF_r(t)\,dt} = \frac{\int_0^{TH} a_i \cdot [C_i(t)]\,dt}{\int_0^{TH} a_r \cdot [C_r(t)]\,dt}$$

where *TH* is the time horizon, *RFi* is the global mean RadiativeForcing(RF) of component *i*, *ai* is the RF per unit mass increase in atmospheric abundance of component *i* (radiative efficiency), [*Ci*(*t*)] is the time-dependent abundance component of *i*, the corresponding quantities for the reference gas (*r*) are in the denominator. The numerator and denominator are called the absolute global warming potential (AGWP) of *i* and *r* respectively. All GWPs use CO_2 as the reference gas.

Basing on the above formula the global warming potential was calculated for 20, 100 and 500 years and shown in the following table 2.2. As there are some uncertainties in the above formula, the global warming potential has been discontinued and Global temperature potential is being calculated as shown in table 2.2 below:

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency ($W\ m^{-2}\ ppb^{-1}$)	Global Warming Potential for Given Time Horizon: SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]1.4×10^{-5}	1	1	1	1
Methane[c]	CH_4	12[c]	3.7×10^{-4}	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03×10^{-3}	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990
Halon-1301	$CBrF_3$	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	$CBrClF_2$	16	0.3		4,750	1,890	575
Halon-2402	$CBrF_2CBrF_2$	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl_4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH_3Br	0.7	0.01		17	5	1
Methyl chloroform	CH_3CCl_3	5	0.06		506	146	45
HCFC-22	$CHClF_2$	12	0.2	1,500	5,160	1,810	549
HCFC-123	$CHCl_2CF_3$	1.3	0.14	90	273	77	24
HCFC-124	$CHClFCF_3$	5.8	0.22	470	2,070	609	185
HCFC-141b	CH_3CCl_2F	9.3	0.14		2,250	725	220
HCFC-142b	CH_3CClF_2	17.9	0.2	1,800	5,490	2,310	705
HCFC-225ca	$CHCl_2CF_2CF_3$	1.9	0.2		429	122	37
HCFC-225cb	$CHClFCF_2CClF_2$	5.8	0.32		2,030	595	181
Hydrofluorocarbons							
HFC-23	CHF_3	270	0.19	11,700	12,000	14,800	12,200
HFC-32	CH_2F_2	4.9	0.11	650	2,330	675	205
HFC-125	CHF_2CF_3	29	0.23	2,800	6,350	3,500	1,100
HFC-134a	CH_2FCF_3	14	0.16	1,300	3,830	1,430	435
HFC-143a	CH_3CF_3	52	0.13	3,800	5,890	4,470	1,590
HFC-152a	CH_3CHF_2	1.4	0.09	140	437	124	38
HFC-227ea	CF_3CHFCF_3	34.2	0.26	2,900	5,310	3,220	1,040
HFC-236fa	$CF_3CH_2CF_3$	240	0.28	6,300	8,100	9,810	7,660
HFC-245fa	$CHF_2CH_2CF_3$	7.6	0.28		3,380	1030	314
HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	0.21		2,520	794	241
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15.9	0.4	1,300	4,140	1,640	500
Perfluorinated compounds							
Sulphur hexafluoride	SF_6	3,200	0.52	23,900	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	0.21		12,300	17,200	20,700
PFC-14	CF_4	50,000	0.10	6,500	5,210	7,390	11,200
PFC-116	C_2F_6	10,000	0.26	9,200	8,630	12,200	18,200

Table 2.2. Global warming potential for 20, 100 and 500 years

7. Global Temperature Potential:

Due to the uncertainties and disagreement on the definition of GWP, GTP was proposed. It is a new relative emission metric. The GTP is defined as the ratio between the global mean surface temperature change at a given future time horizon (TH) following an emission (pulse or sustained) of a compound *x* relative to a reference gas *r.* The formula is as below:

$$GTP_x^{TH} = \frac{\Delta \bar{T}_x^H}{\Delta T_r^H}$$

where ΔT_x^H denotes the global mean surface temperature change after *H* years following an emission of compound *x*.

8. Paleo-Climatology: **Reconstructing Past Climates**

Paleo- climatic estimations are made by Two methods. Direct measurements of past change: Measurement of ground temperature variations, gas content in ice core air bubbles, ocean sediment pore-water change and glacier extent changes. Proxy measurements: Estimating the change in physical chemical, and biological parameters that reflect past change in the environment where the proxy carrier grew or existed.

What are the Proxy methods?

There are various Proxy methods. Tree ring records are generally the most accurate proxy method. These are accurate to the year, season or even thousands of years back. There are a host of other proxies that also have annual layers or bands (e.g., corals, varved sediments, some cave deposits, some ice cores)

A wide range of evidence exists to allow climatologists to reconstruct the Earth's past climate. This evidence can be grouped into three general categories.

The first category is **meteorological instrument records**. Common climatic elements measured by instruments include temperature, precipitation, wind speed, wind direction, and atmospheric pressure. However, many of these records are temporally quite short as many of the instruments used were only created and put into operation during the last few centuries or decades. Another problem with instrumental records is that large areas of the Earth are not monitored. Most of the instrumental records are for locations in populated areas of Europe and North America. Very few records exist for locations in less developed countries (LDCs), in areas with low human populations, and the Earth's oceans. Over the last half century many meteorological stations have been added in land areas previously not covered. Another important advancement in developing a global record of climate has been the recent use of remote satellites.

Written documentation and **descriptive accounts** of the weather make up the second general category of evidence for determining climate change. Weather phenomena commonly described in this type of data includes the prevailing character of the seasons of individual years, reports of floods, droughts, great frosts, periods of bitter cold, and heavy snowfalls. Large problems exist in the interpretation of this data because of its subjective nature.

Many types of **physical** and **biological data** can provide fossil evidence of the effects of fluctuations in the past weather of our planet. Scientists refer to this information as "**proxy data**" of past weather and climate. Examples of this type of data include tree ring width and density measurements, fossilized plant remains, insect and pollen frequencies in sediments, moraines and other glacial deposits, marine organism fossils, and the isotope ratios of various elements. Scientists using this type of data assume uniformity in the data record. Thus, the response measured from a physical or biological character existing today is equivalent to the response of the same character in the past. However, past responses of these characters may also be influenced by some other factor not accounted for. Some common examples of proxy data include:

Glacial Ice Deposits. Fluctuations in climate can be determined by the analysis of gas bubbles trapped in the ice which reflect the state of the atmosphere at the time they were deposited, the chemistry of the ice (concentration or ratio of major ions and isotopes of oxygen and hydrogen), and the physical properties of the ice.

Biological Marine Sediments. Climate change can be evaluated by the analysis of temporal changes in fossilized marine fauna and flora abundance, morpological changes in preserved organisms, coral deposits, and the oxygen isotopic concentration of marine organisms.

Inorganic Marine Sediments. This type of proxy data includes clay mineralogy, aeolian terrestial dust, and ice rafted debris.

Terrestrial Geomorphology and Geology Proxy Data. There are a number of different types of proxy data types in this group including glacial deposits, glacial erosional features, shoreline features, aeolian deposits, lake sediments, relict soil deposits, and speleothems (depositional features like stalactites and stalagmites).

Terrestial Biology Proxy Data. Variations in climate can be determined by the analysis of biological data like annual tree rings, fossilized pollen and other plant macrofossils, the abundance and distribution of insects and other organisms, and the biota in lake sediments.